Prospects for the Determination of Higgs boson properties at LHC

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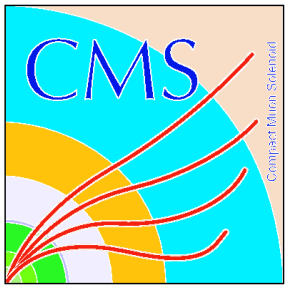

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SUSY2007, Karlsruhe, 28.7.07

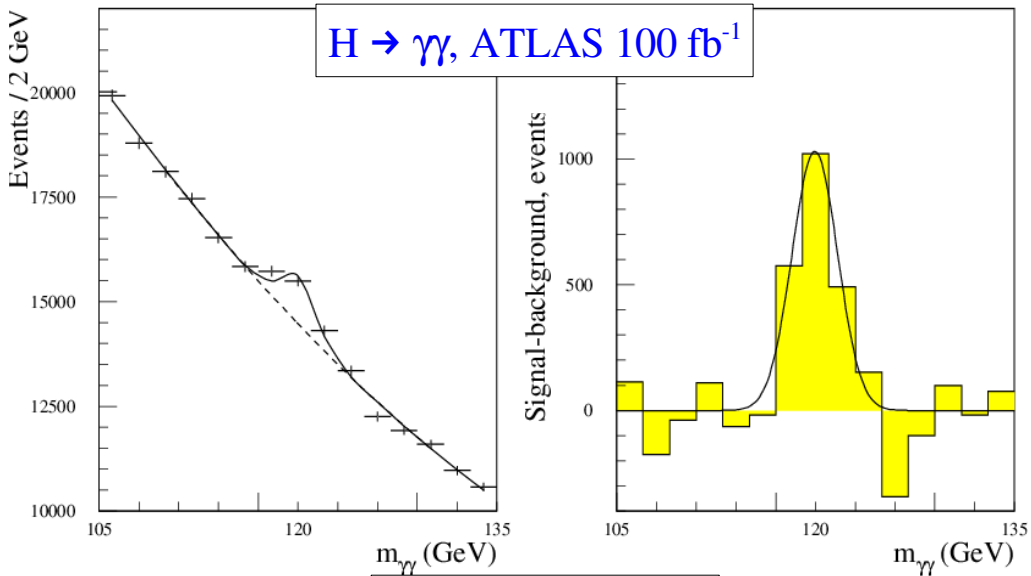
Introduction

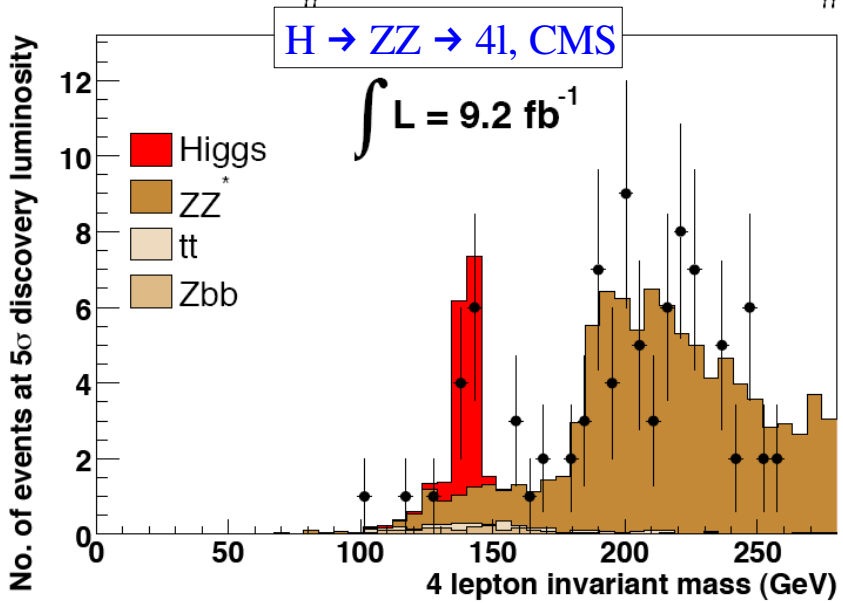
- One major objective at the LHC: Understand electroweak symmetry breaking
  - Many ways to describe it in theory
    - Discovery of a new particle by itself might not provide a unique answer
  - Model parameters need to be measured to fix predictions
  - Predictions need to be tested
    $\Rightarrow$ Determination of particle properties will be important

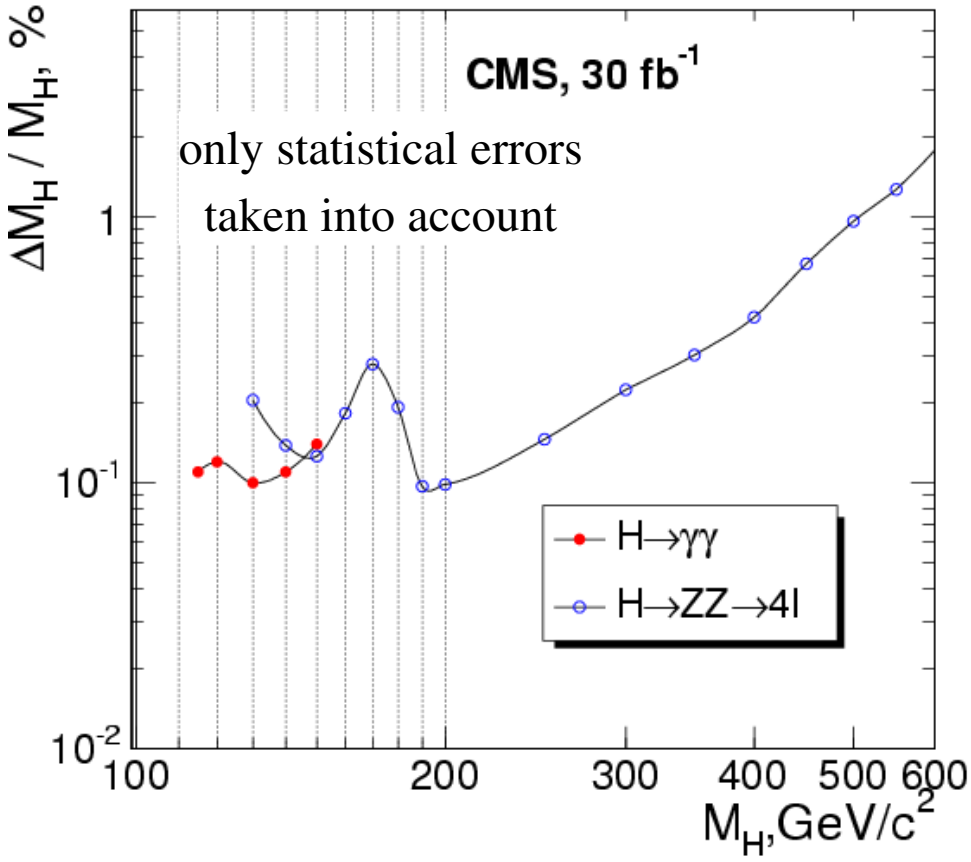
- Properties of the Higgs boson to be determined include:
  - Mass, Width
  - Couplings to gauge bosons, fermions, itself
  - Quantum numbers: Charge, spin, CP

Mass

- Fit mass peak in H → γγ, H → ZZ → 4l
  - Small relative uncertainty: < 0.3% up to $m_H \approx 300$ GeV, depending on $\int L$

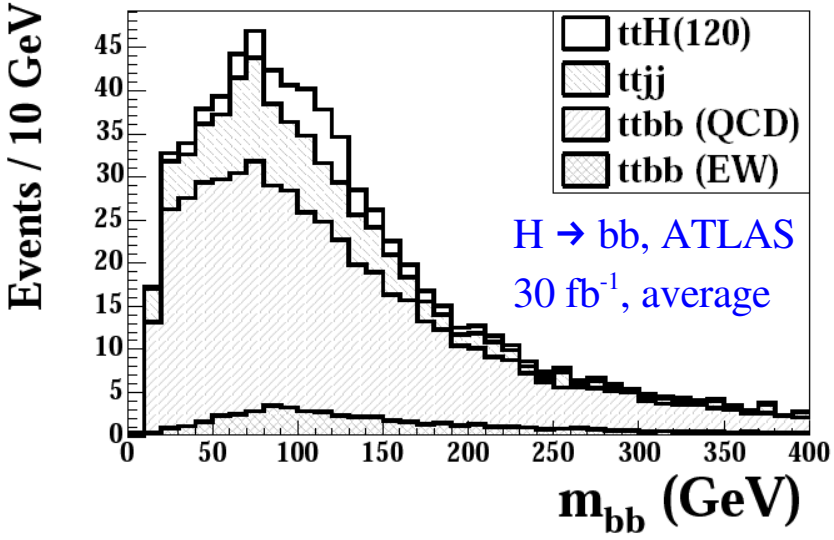


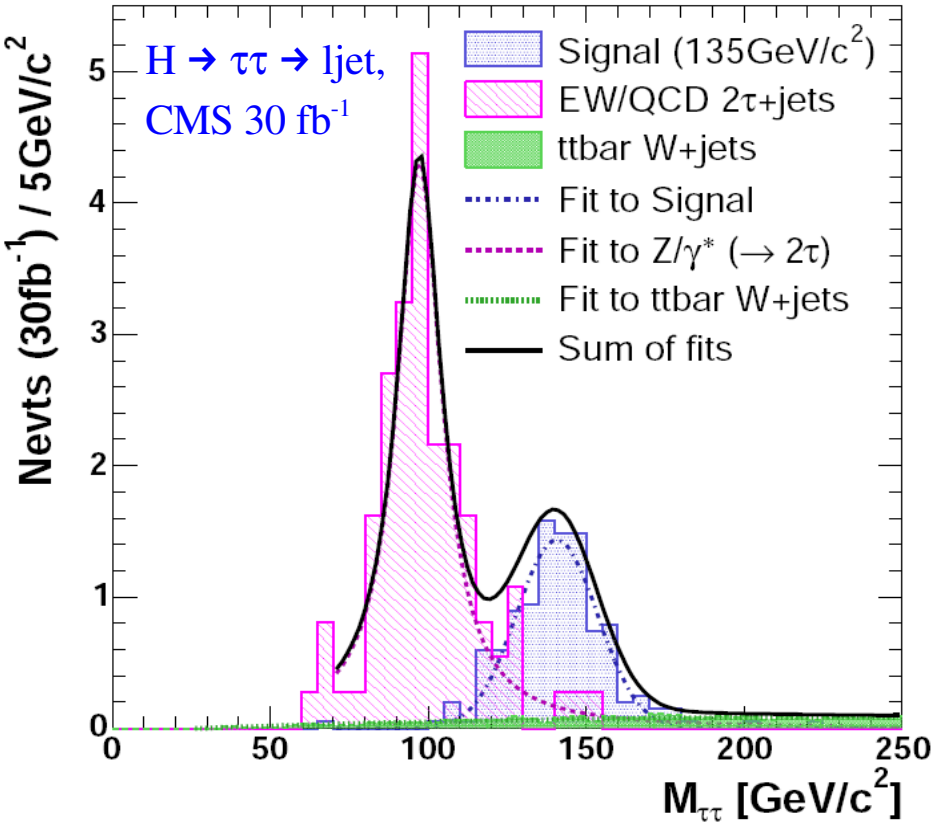




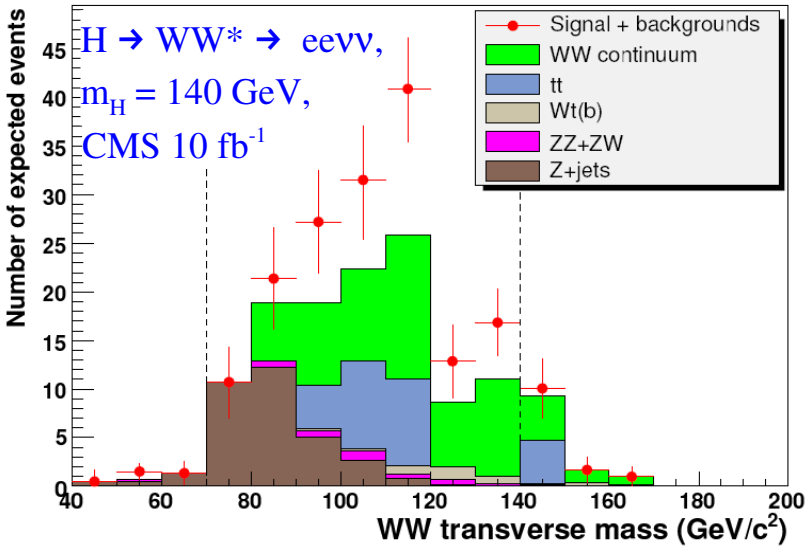
Mass

- Measurement more difficult if H→ γγ, H → ZZ are suppressed
  - Reconstruct mass in H→ bb, H → ττ (using collinear approximation):





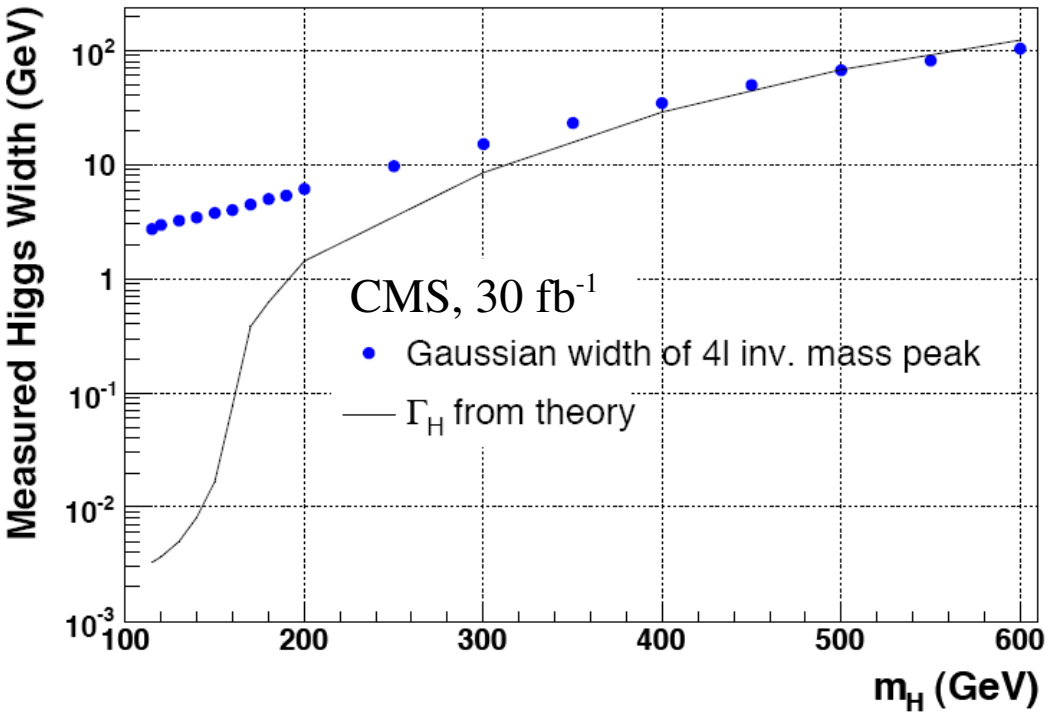
  - Fit transverse mass in H→ WW:

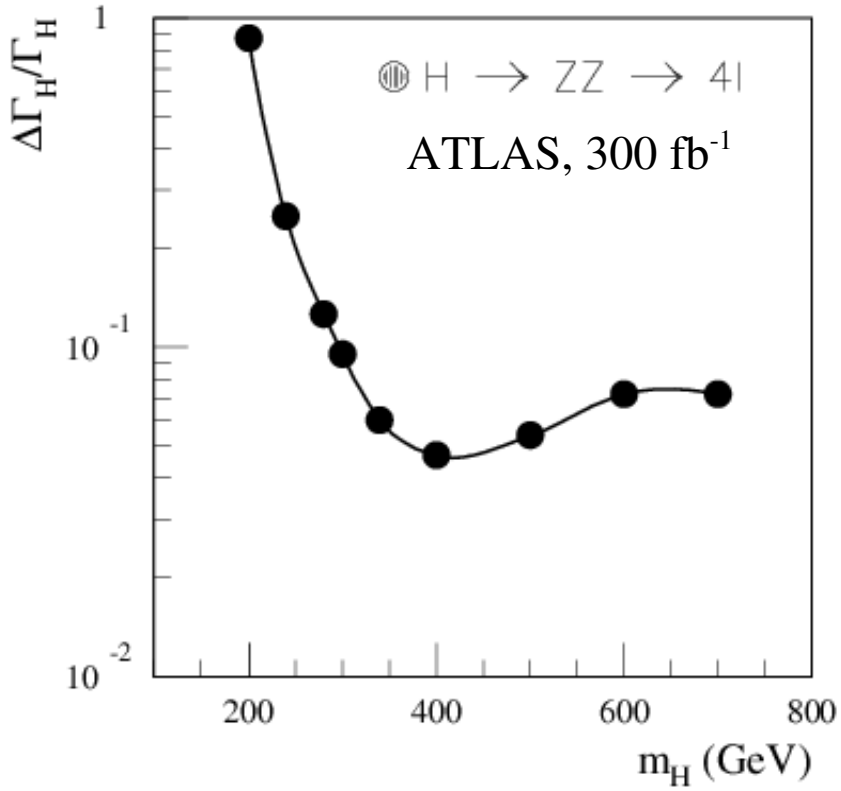


- M_H precision observable for SM Higgs, fixes model predictions (couplings, width...)
- Further measurements test the SM

Width

- Mass resolution ≫ width of Higgs boson for $m_H < 200$ GeV
  - direct measurement for $m_H > 250$ GeV, precision < 10% above 300 GeV





Couplings to Fermions and Gauge Bosons

- Likelihood fit to expected event numbers from ATLAS analyses for 13 channels
- Systematic errors (luminosity, detector effects, background normalisation, theoretical, PDF uncertainties) taken into account

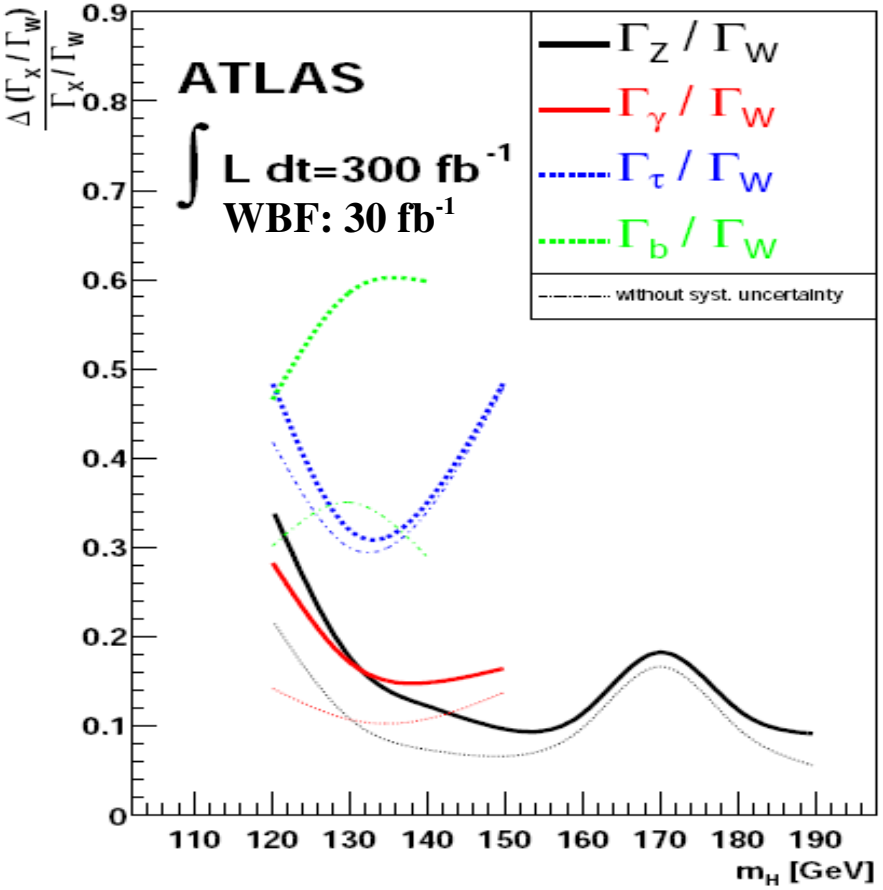
$$\sigma \cdot BR \propto \Gamma_{prod.} \frac{\Gamma_{decay}}{\Gamma_H}$$

- Γ_H not directly measured
  - Model independent: only fit of ratios of partial widths

- Assumptions: Spin 0, CP even, only one Higgs boson contributes

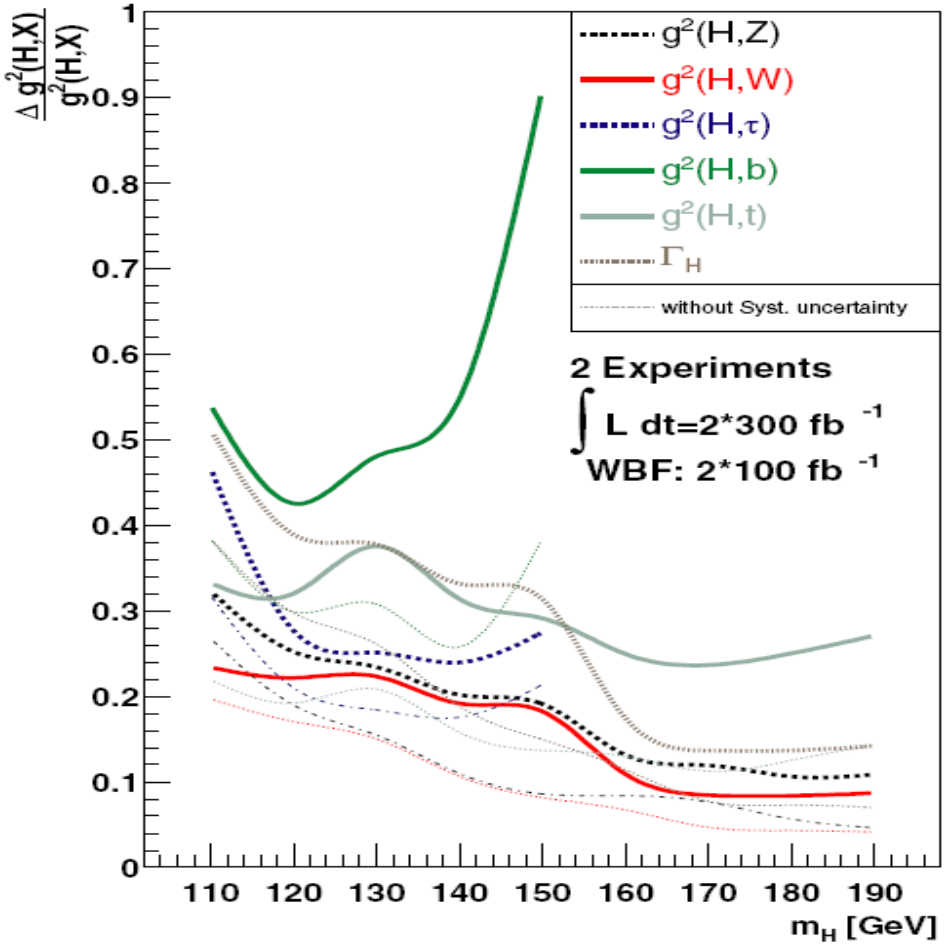
- Ratios with respect to Γ_W:
  H → WW channel with highest precision in mass range

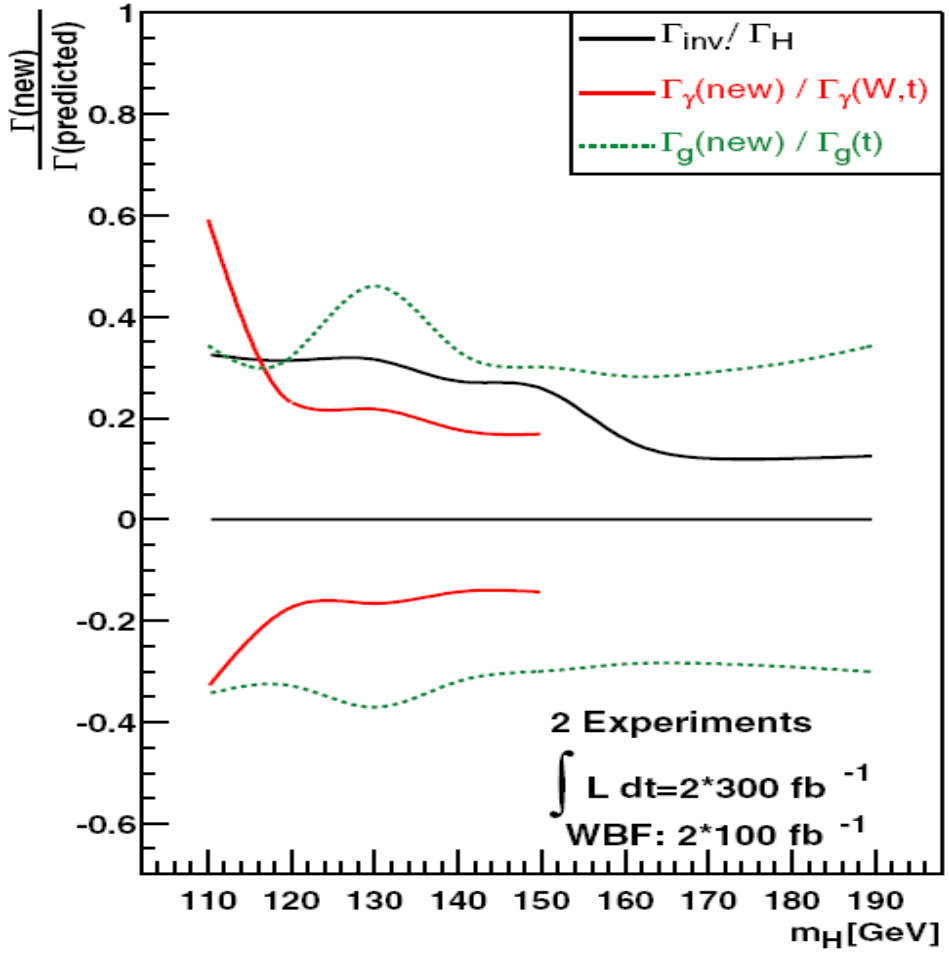
- Relative error 10% - 35% for Γ_Z, Γ_γ ratios, between 30% and 60% for Γ_τ, Γ_b ratios



Absolute Couplings and Width

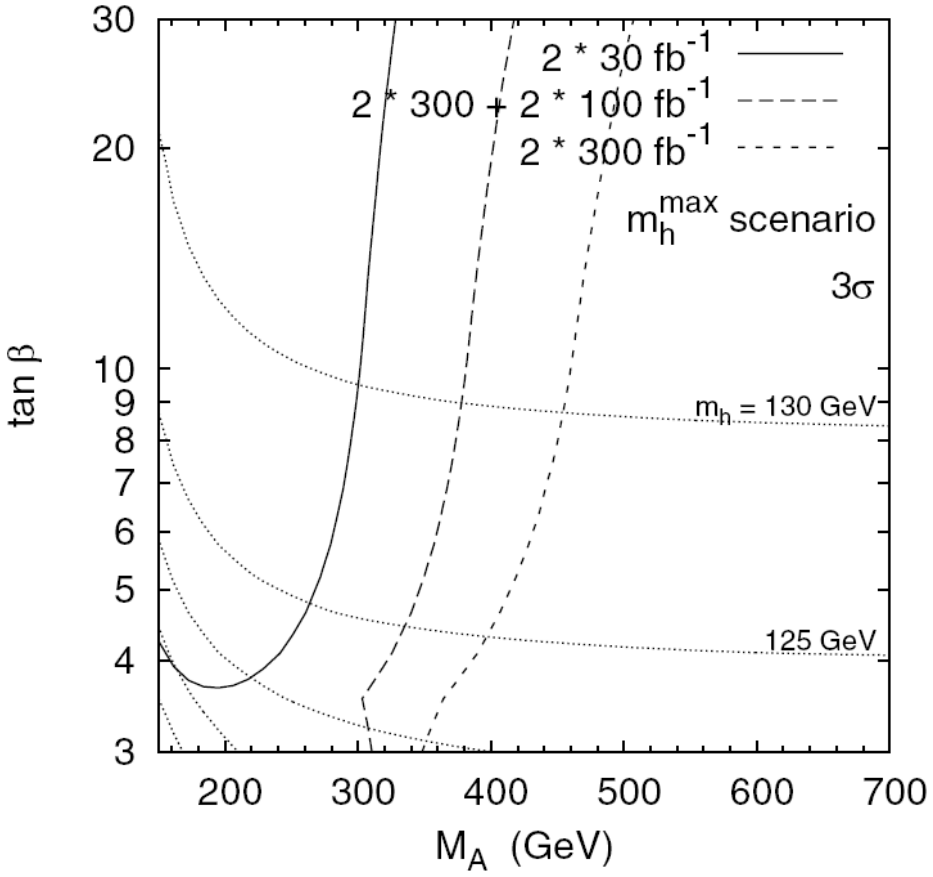
- Lower bound on Γ_H from observation of Higgs boson production
- Additional Assumption: $\Gamma_V < \Gamma_V^{SM}$ (V = W/Z), valid in multi-Higgs doublet models
- Upper bound from constraint and measurement of $\Gamma_V^2/\Gamma_H \Rightarrow$ fit absolute couplings and Γ_H, allowing for unknown particles in Hgg, Hγγ loops and undetected decays





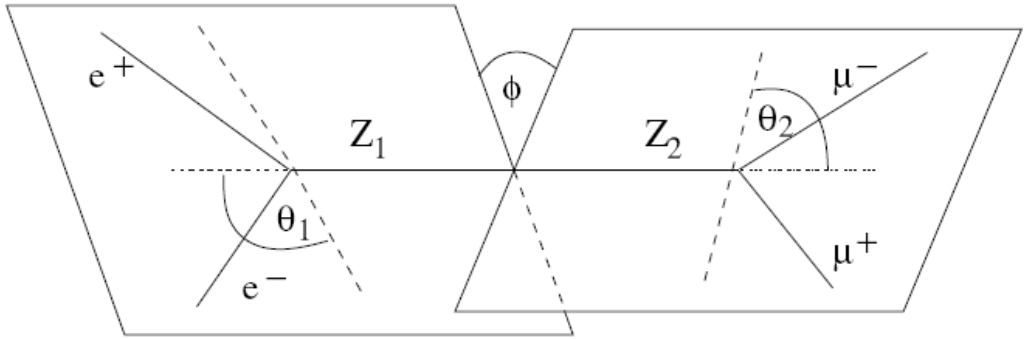
Exclusion of MSSM Scenarios

- Use coupling fit to calculate expected exclusion of MSSM parameter regions
  - Assume MSSM event rates and statistical errors
  - Identify regions in which SM shows discrepancy of $\Delta\chi^2 \geq 9$ (“3σ”)



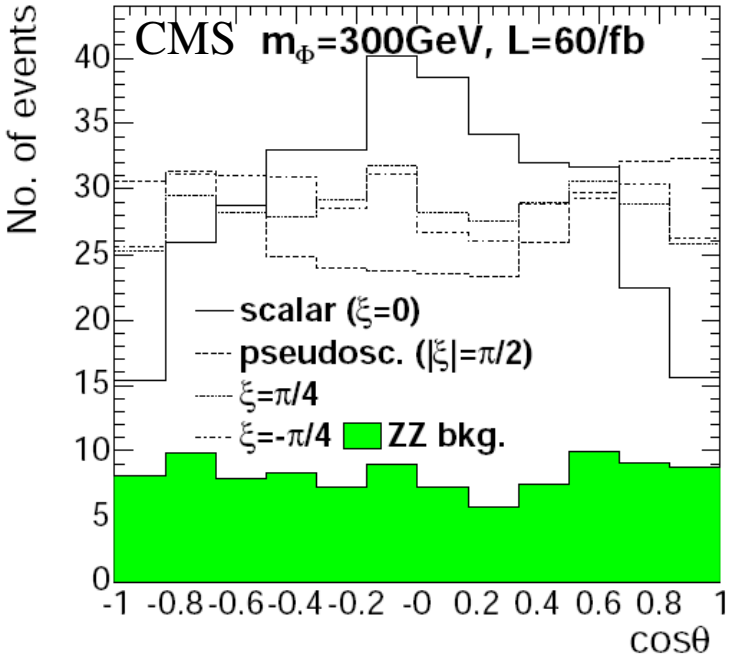
Spin and CP Quantum Numbers

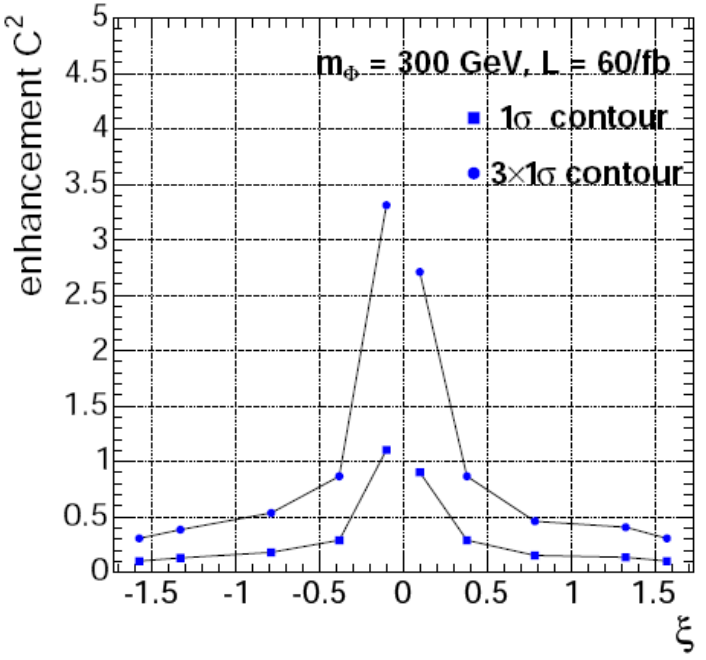
- No production in Hgg and decay in Hγγ for Spin 1
- Spin and CP affect angular distributions of decay leptons in H → ZZ → 4l



- Observables in H → ZZ → 4l:
  - Angle ϕ between planes spanned by leptons
  - angle θ between negatively charged lepton in Z rest frame and Z in Higgs rest frame

- H → ZZ → 2e2μ
- SM vertex + tanξ /m_V^2 times scalar CP odd coupling contribution
- tt̄, Zbb̄ backgrounds suppressed by cuts





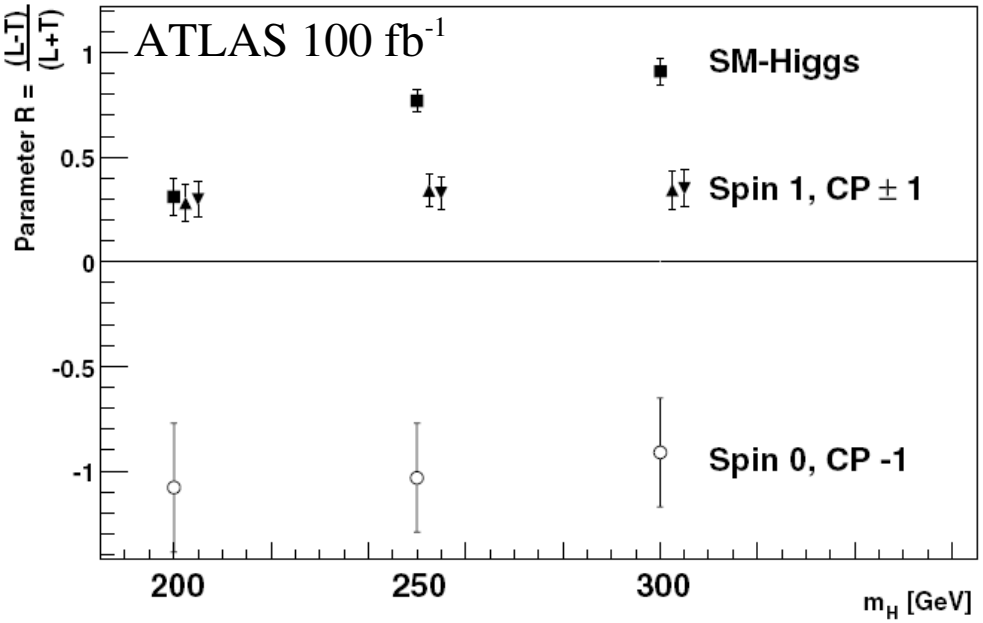
Spin and CP Quantum Numbers

- H → ZZ → 4l, test for combinations of Spin and CP quantum numbers
- Parametrisations of angular distributions used in fit:

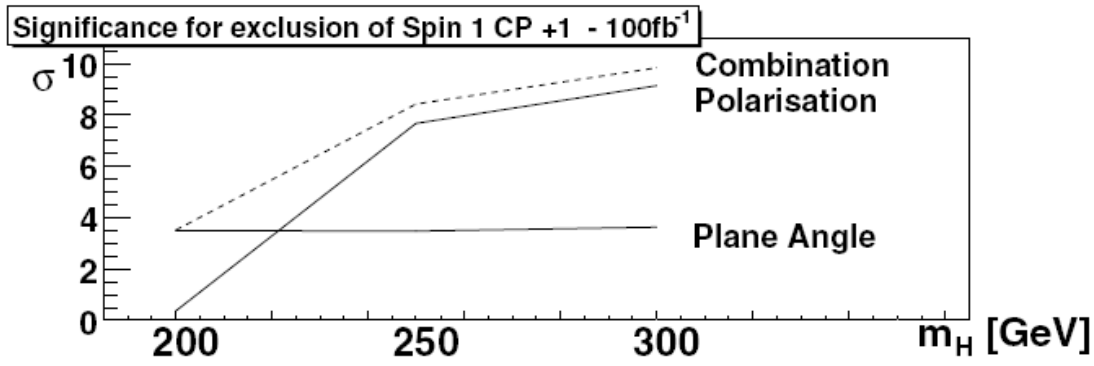
$$F(\phi) = 1 + \alpha \cdot cos(\phi) + \beta \cdot cos(2\phi)$$

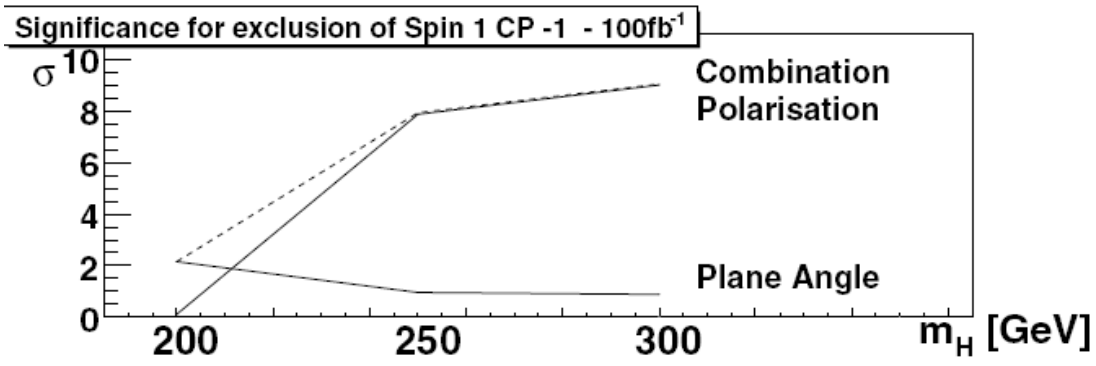
$$G(\theta) = T \cdot (1 + cos^2(\theta)) + L \cdot sin^2(\theta)$$

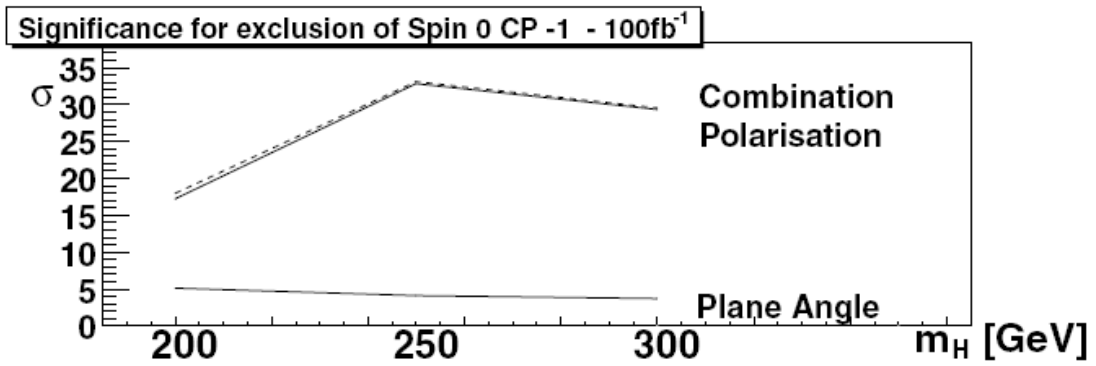
$$R \equiv \frac{L - T}{L + T}$$



Expected deviations from SM divided by expected SM uncertainties:

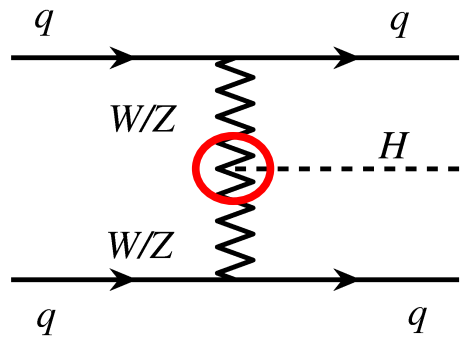






Structure of HVV Couplings

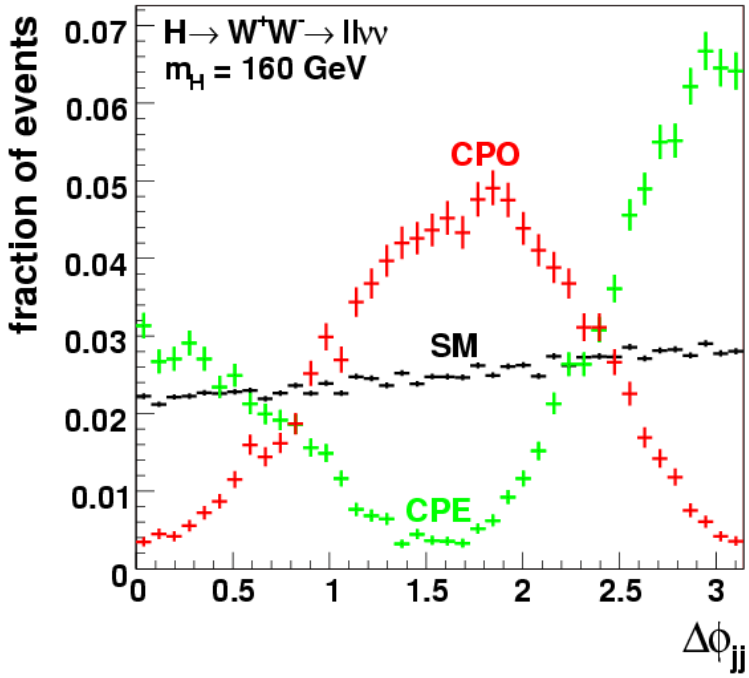
- Study of HVV (V = W/Z) coupling structure in VBF, using fast detector simulation
- Scalar vertex with SM + CP even/CP odd dimension 5 terms
- Observable: $\Delta\phi$ between tagging jets



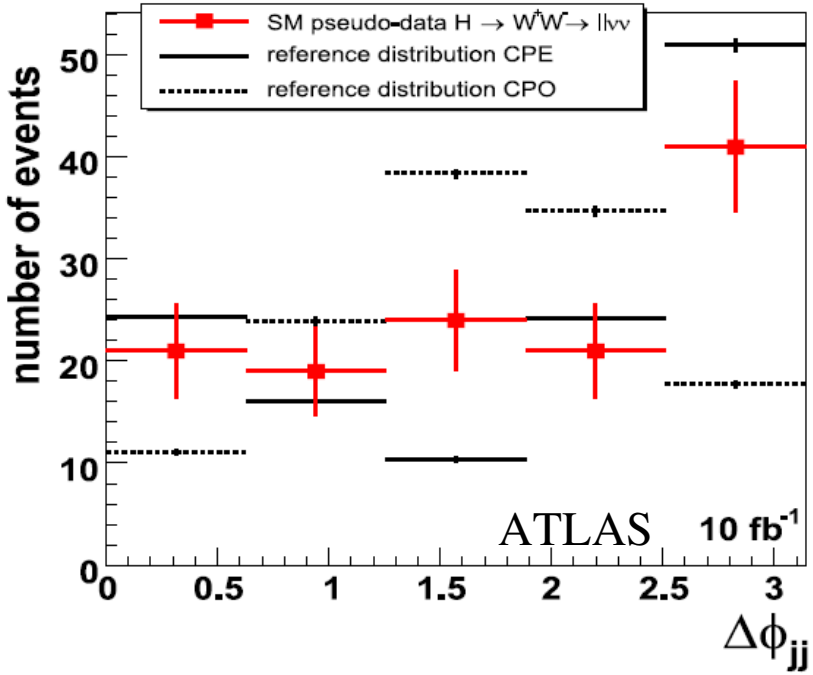
- χ^2 hypothesis test to determine dominant coupling
- Channels: $H \rightarrow \tau\tau$ at $m_H = 120$ GeV

  $H \rightarrow WW \rightarrow ll\nu\nu$ at $m_H = 160$ GeV

Signal $H \rightarrow WW$, high statistics, after cuts:



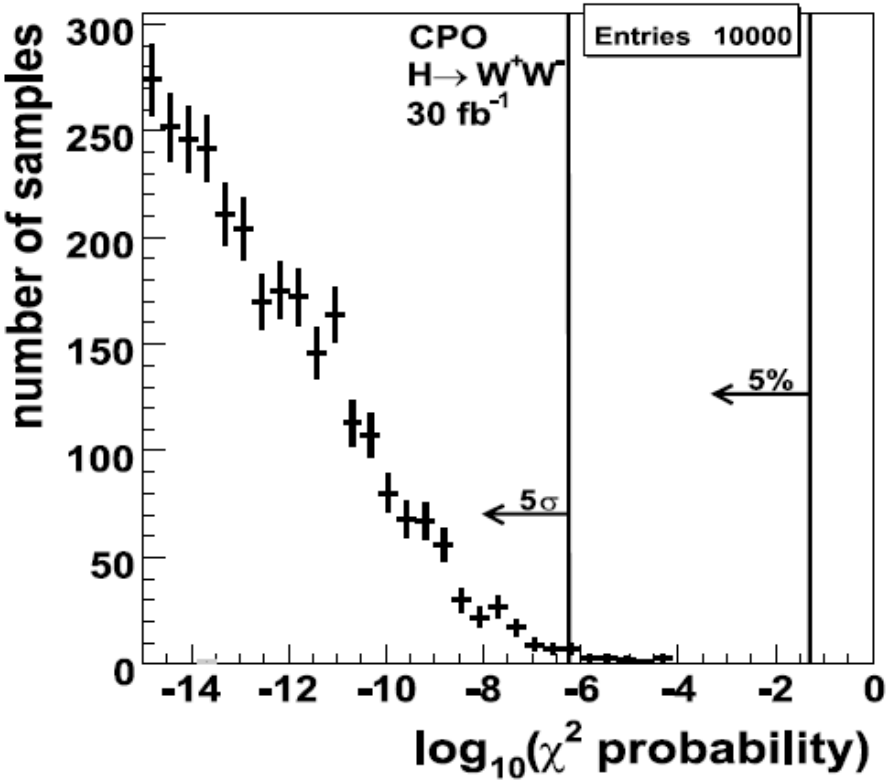
SM pseudo-data including backgrounds, compared to non-SM reference distributions:

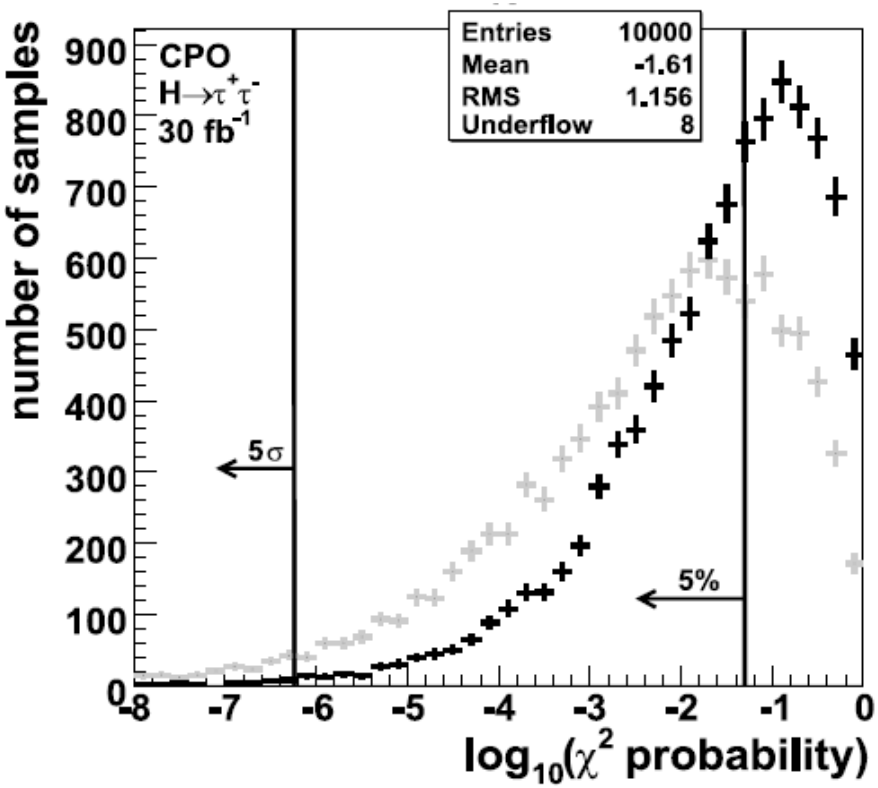


Structure of HVV Couplings

- Test repeated for 10 000 Standard Model pseudo-data samples

CP odd coupling hypothesis:



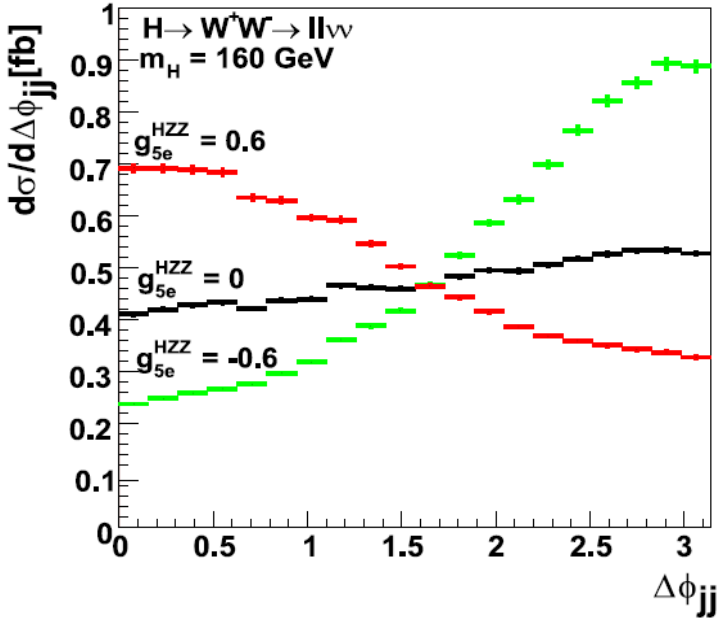


- Median deviation of SM from CPE CPO
  - H → WW 10 fb^{-1}: 5.4 σ 4.6 σ
  - H → ττ 30 fb^{-1}: 2.5 σ 2.0 σ

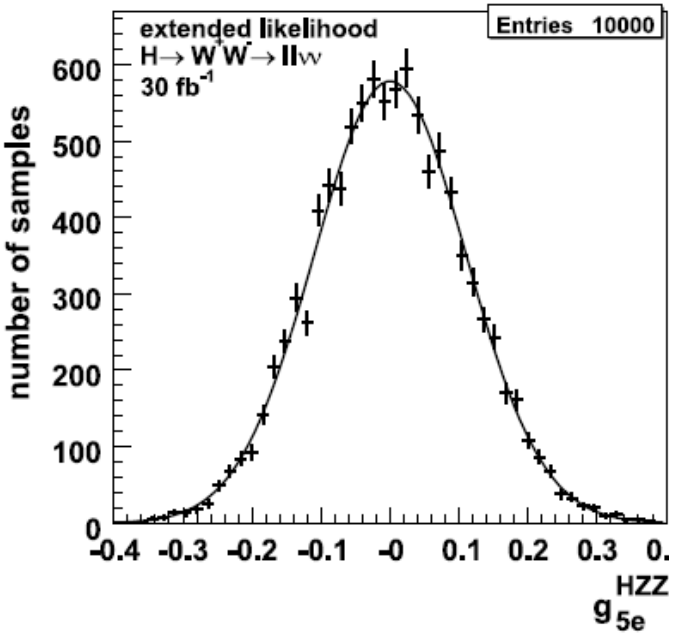
Structure of HVV Couplings

- Likelihood fit: SM+ contribution by CP even effective coupling
- Observe interference in $\Delta\phi_{jj}$ distribution

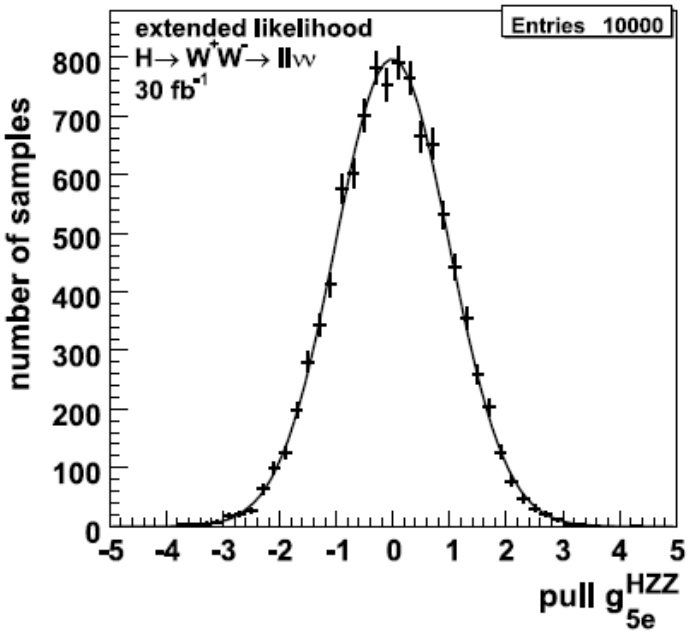
Signal, high statistics:



Fit results effective coupling:



Pulls of fit results:



- Expected sensitivity ($g_{5e}^{HZZ} = 1/\cos^2\theta_W$ gives SM cross section for pure CPE coupling):

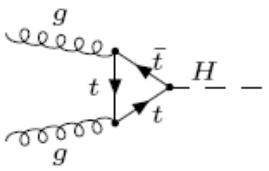
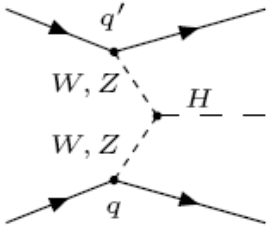
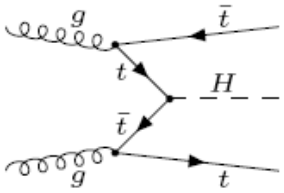
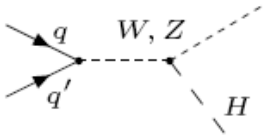
	$\sigma(g_{5e}^{HZZ})$	$\sigma(\text{pull}(g_{5e}^{HZZ}))$
H → WW 30 fb^{-1}:	0.11	1.00
H → ττ 30 fb^{-1}:	0.24	0.97

- 10% uncertainty on background rate: additional uncertainty of order 0.02

Summary

- Mass measurement considered possible with relative uncertainty of 0.1% - 1%
- Higgs boson width directly accessible above 250 GeV
  - Fit below 200 GeV with assumption $\Gamma_V < \Gamma_V^{SM}$
  - Expected precision < 10% (direct H → ZZ), 15% - 50% (fit)
- Determination of relative widths through fit to results from different channels
  - Fit of absolute couplings possible with additional assumptions
  - Typical expected precision few 10%
- Spin, CP determination in H → ZZ → 4l studied for masses above 200 GeV
  - > 5σ discrimination between SM and non-SM cases above 230 GeV expected
- Structure of HVV couplings and CP properties studied in vector boson fusion
  - > 5σ exclusion of non-SM cases at 160 GeV, > 2σ appears possible at 120 GeV
  - Fit sensitive to interference between SM and CP even effective coupling

Channels Used in Fit of Couplings

Production		Decay	Mass range
	GF: Gluon Fusion ($gg \to H$)	$H \to ZZ^{(*)} \to 4l$	110 GeV - 200 GeV
		$H \to WW^{(*)} \to l\nu\, l\nu$	110 GeV - 200 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	WBF: Weak Boson Fusion ($qq\,H$)	$H \to ZZ^{(*)} \to 4l$	110 GeV - 200 GeV
		$H \to WW^{(*)} \to l\nu\, l\nu$	110 GeV - 190 GeV
		$H \to \tau\tau \to l\nu\nu\, l\nu\nu$	110 GeV - 150 GeV
		$H \to \tau\tau \to l\nu\nu\, \mathrm{had}\nu$	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 150 GeV
	$t\bar{t}H$	$H \to WW^{(*)} \to l\nu\, l\nu\, (l\nu)$	120 GeV - 200 GeV
		$H \to b\bar{b}$	110 GeV - 140 GeV
		$H \to \tau\tau$ (not included)	110 GeV - 150 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	WH	$H \to WW^{(*)} \to l\nu\, l\nu\, (l\nu)$	150 GeV - 190 GeV
		$H \to \gamma\gamma$	110 GeV - 120 GeV
	ZH	$H \to \gamma\gamma$	110 GeV - 120 GeV

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